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COMPARISON OF THE BEHAVIOR OF HARDWOOD PACKING TESTED UNDER CONTROLLED CONDITIONS WITH IN SITU OBSERVATIONS

W.D. Gallant and D. Payne

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COMPARISON OF THE BEHAVIOR OF HARDWOOD PACKING TESTED UNDER CONTROLLED CONDITIONS WITH IN SITU OBSERVATIONS

by

W.D. Gallant* and D. Payne**

SUMMARY

This report compares the results of full scale compressive testing on hardwood packs with data produced from in situ observations. The work performed was a cooperative research effort of the CANMET Cape Breton Coal Research Laboratory (CBCRL) and Cape Breton Development Corporation (CBDC) in conjunction with the United States Bureau of Mines (USBM). The purpose of the work was to develop a more precise description of pack load/strain behavior. Information produced will benefit analysis of gateroad behavior to improve design.

Typical pack configurations of local materials were tested in the mine roof simulator (MRS) of the Pittsburgh Research Center USBM in September 1989. Data from in situ observations was superimposed on the MRS results.

In general, the in situ results indicated lower load bearing capacities than that of the MRS data for equivalent strain. Trends of the two data sets are similar for the most part. Discussion on the differences is included in the report.

Information from the in situ and MRS testing is used to propose an approximation of the in situ load/strain relationship. These approximations are intended to provide the capability of determining pack load indirectly through pack strain, resulting in reduced instrumentation costs and ability to back analyze gateside pack performance.

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*Senior Technologist, Cape Breton Coal Research Laboratory, CRL, CANMET, Energy, Mines and Resources Canada, Sydney and **Mining Engineer, Cape Breton Development Corporation, Sydney.

COMPARAISON DU COMPORTEMENT DE GARNITURES DE BOIS DUR ESSAYEES DANS DES CONDITIONS CONTROLEES AVEC DES OBSERVATIONS DE TERRAIN

par

W.D. Gallant* et D. Payne**

RESUME

Le présent rapport compare les résultats d'essais de compression à l'échelle réelle sur des garnitures de bois dur avec des données provenant d'observations sur le terrain. La recherche a été effectuée par le Laboratoire de recherche sur le charbon du Cap-Breton (LRCCB) de CANMET et la Société de développement du Cap-Breton (SDCB) en collaboration avec l'United States Bureau of Mines (USBM). Le but de la recherche était de préciser la description du comportement des garnitures en termes de charge et de déformation. L'information produite facilitera l'analyse du comportement des galeries de desserte pour en améliorer la conception.

Des configurations types de garnitures à base de matériaux locaux ont été essayées dans le simulateur de toit de mine (STM) du Centre de recherche de Pittsburgh de l'USBM en septembre 1989. Des données d'observations sur le terrain ont été superposées aux résultats du STM.

En général, les résultats sur le terrain ont révélé des capacités de soutenir des charges inférieures à celles des données du STM pour des déformations équivalentes. La plupart des tendances des deux ensembles de données sont semblables. Les différences sont analysées dans le rapport.

L'information découlant des essais sur le terrain et des essais du STM est utilisée pour proposer une approximation de la relation charges/déformations sur le terrain. Ces approximations serviront à calculer indirectement les charges exercées sur les garnitures à partir des déformations des garnitures, permettant ainsi de réduire les coûts d'instrumentation et d'analyser à posteriori le rendement des garnituresen bordure des galeries.

*Technologue principal, Laboratoire de recherche sur le charbon du Cap-Breton, LRC, CANMET, Energie, Mines et Ressources Canada, Sydney.

**Ingénieur minier, Société de développement du Cap-Breton, Sydney.

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INTRODUCTION

The Cape Breton Development Corporation (CBDC) and the Cape Breton Coal Research Laboratory (CBCRL) have been examining the behavior of gateroads behind advancing longwall faces. Hardwood packing is an integral part of the gateroad support. To enable a better understanding of the behavior of the gateroad, a series of nine full scale tests were performed on typical pack configurations used in the Sydney Coalfield.

The testing was uniaxial compressive with loading normal to the packs. The mine roof simulator (MRS) of the Pittsburgh Research Center, USBM undertook the testing. Results produced are to be used in back analysis of field data, hardwood pack design and as a reference for pack design using alternative materials.

BACKGROUND

PACKING IN THE SYDNEY COALFIELD

Gateside packing is a method of supporting gateroads of advancing longwall faces. Gateroads constructed behind an advancing longwall coal face are supported on one side by a continuous coal pillar. The void left by mining coal is supported by the placement of a pack near the road side.

A gateside pack will develop resistive force to roof convergence as it is compressed (1). The pack must react in a suitable manner until the secondary stresses around the gateroad, a consequence of coal extraction, have been redistributed to restore equilibrium. It is important that such gateside packs must not destroy the natural roof beams that form over the gateroads by the application of resistance to loading that is either too great or to small. They must allow limited convergence to occur in a controlled manner to such points that they accept final load without further convergence.

In the Sydney Coalfield, packs have historically been constructed of either rubble, softwood, and/or hardwood. Presently, hardwood chocks (150 mm x 150 mm section) are used. Figure 1 presents the general load/yield relationships of several pack materials (2).

FIELD INSTRUMENTATION

To observe the behavior of the pack and roadway, instrumentation sites have been installed in Lingan Mine (3,4). Pack load is measured by placing flat jacks in between the hardwood layers as the pack is constructed. Pressure indicated is extrapolated to the entire contact surface of the pack to determine load bearing. Convergence is measured with convergence pins and/or pack struts. Convergence is converted to pack strain with reference to the extracted height. Roadway closure, floor heave and other parameters are observed to quantify the behavior of the roadway.

The flat jacks used to measure load are 150 mm x 150 mm. The stress on the contact surface of the intersection of two chocks is measured with the flat jack. This can be a small proportion of a pack. To better represent the load over the pack, several cells are installed. Results have shown wide variations in the load of each cell.

Deformation of the pack is usually severe. Cells placed in the pack are subject to this deformation which cause inaccuracies in the load they indicate. The stress/strain characteristics of the pack are not precisely clear. This information is key to the development of a rational support design in the Sydney Coalfield. Observations of gateroad behavior compared with pack characteristics will allow the development of improved designs.

FUTURE APPLICATIONS

Hardwood chocks and other wood products have been used in mines since mining began. Alternatives to wood are being pursued, to reduce fire risk and provide a material that is easier to transport (pneumatic, hydraulic)(5). The need to supply materials at increased rates will predicate changing material.

Pillarless retreat mining is being planned in the Sydney Coalfield. Packing will be required to allow the reuse of roadways. Pack designs will need to provide sufficient support and allow for rapid advancement.

Designs incorporating alternative materials can be developed by referencing the performance of hardwood packs.

TEST DESCRIPTION

HARDWOOD CHOCKS

The hardwood chock blocks used were ordered from a regular supplier to CBDC. Packed onto a transport truck they were delivered to the Pittsburgh Research Center several weeks before testing.

The chock wood was predominantly maple or birch with other species accounting for a small proportion. Most of the chocks contained the "tree hearts". Dimensions of the chocks were 150 mm x 150 mm (6" x 6") in section with a length of 0.75 m (2½') or 1.5 m (5'). Moisture content of the wood prior to testing was typically greater than 25% for the 1.5 m sticks and greater than 30% for the 0.75 m sticks. The above conditions are typical of the hardwood used by CBDC.

MINE ROOF SIMULATOR

The Pittsburgh Research Center of the United States Bureau of Mines (USBM) operates a mine roof simulator (MRS). The MRS is a computer controlled electro-mechanical hydraulic press designed to provide a realistic simulation of mine roof behavoir (6). The simulator has 6.1 m x 6.1 m (20' x 20') platens with a 4.9 m (16') maximum height. Vertical load of 13.3 MN (3000 kip) can be applied over a 0.6 m (24") stroke. Horizontal loads of 7.1 MN (1600 kip) can be applied over a 0.4 m (16") stroke.

Full scale packs easily fit in the MRS. Capacity of the MRS is sufficient to provide pack loading to levels achieved in the Sydney Coalfield, based on 0.55 m (22") stroke.

PACK CONFIGURATIONS

A series of nine configurations were tested. The percentage solid was varied with the 1.5 m x 1.5 m packs (Figures 2 and 3). The same was done for the 0.75 m x 0.75 m. Tests were also conducted on various heights of 0.75 m x 0.75 m chocks 40% solid. Table 1 presents the configurations tested.

Construction of the packs took place in the center of the MRS platens. Layers of chocks were placed, alternating direction with each layer. The pack was built square to the platens. Wedges were not used to tighten the pack.

LOADING PROCEDURE

The top platen of the MRS was lowered to within 25 mm (1") of pack. Advance rate of the lower platen was set to 13 mm/m (0.5 in/m). Load was applied normal to the pack at this constant rate of strain until the end test criteria of the MRS were reached, 13.3 MN (3000 kip) load or 0.55 m (22") stroke.

Packs were photographed prior to and after testing. Video recording of deformation was made with black and white CCTV cameras. Data collected during testing was reduced to plots of vertical force versus displacement of each test. Plots of the test results were digitize at CBCRL and converted to plots of load/meter run (MN) versus strain (%).

RESULTS OF MINE ROOF SIMULATOR TESTS

Figures 4, 5 and 6 show smooth curves with three linear portions representing three phases of loading (6). The first phase from 0 to 5% strain has a steep slope. In this phase, load is consumed rapidly to bend and deform chocks until contact surfaces close together. The second linear phase represents the pack's ability to continuously deform and accept load. Test No. CBDC08 was subjected to the highest strain of 37% load and was still increasing when the test was stopped. The third phase is characterised by a vertical decrease in load after loading was stopped when the end of test criteria was achieved. The load decreased due to creep inherent in this material.

The load bearing capacity increases with the area of contact. Some variations occurred due to the nature of contact. Test No. CBDC05, Table 2, 0.75 m x 0.75 m x 100% reached a maximum load of 5.6 MN at 25.8% strain. Test No. CBDC03, 1.5 m x 1.5 m x 50% reached a maximum load of 9.0 MN at 27.4% strain. The two configurations have equal areas of contact. CBDC03 developed greater load because the pack had free spaces which allowed the chock blocks to indent into the blocks they contacted, increasing the resistance to lateral movement.

The effects of height were examined in Test Nos. CBDC07, CBDC08 and CBDC09. The configurations were 0.75 m x 0.75 m x 40% solid with heights of 1.5 m, 2.1 m and 2.75 m. The curves are similar with increased loads exhibited with increased strain (Figure 6). In Test No. CBDC07, the 2.1

height configuration failed to accept increasing load during the last 2.5% strain of testing.

Although the 1.5 m height configuration accepted the greatest load, variations in load acceptance are not evident due to the normal loading applied. A small horizontal component or uneven load distribution across the pack, common underground, would better demonstrate instability due to large height to width ratios.

COMPARISON OF FIELD OBSERVATIONS WITH MINE ROOF SIMULATOR RESULTS

In situ observations of pack behavior in Lingan Mine have been conducted by CBCRL (3,4,7). The results of those observations are presented in Figures 7 and 8. The averaged values of load, determined by contact area stress, are plotted for 9 East material level, 6 West material level and 7 West coal road. Fitted curves are drawn to illustrate the trend. An additional curve is presented from work by Cain (3).

Comparison of results are illustrated in Figures 9, 10, 11 and 12. Trends of the field observations are plotted with the curves of the MRS data for matching configurations. The following is a point formatted description of the comparisons:

i) 6 West material level, 1.5 m x 1.5 m x 100% solid, Figure 9.

Curve is very similar to the MRS results except it is shifted to the right.

ii) 7 West coal road, 1.5 m x 1.5 m x 100% solid, Figure 9.

Curve has a much smaller slope and much lower ultimate load than the MRS data indicates.

iii) Cain 1985, 1.5 m x 1.5 m x 80% solid, Figure 10.

Initial slope is similar to the MRS data. The curve levels off and remains flat from 10% to 35% strain. This is probably due to the

use of roof to floor closure rather than pack compression to calculate strain. Limitations of the flat jacks to measure stress of the contact area may also be responsible.

iv) 7 West coal road, 0.75 m x 0.75 m x 100% solid, Figure 11.

Curve has similar trend to MRS data but has lower value, the difference increases with strain.

v) 9 East material level, 60% solid, Figure 12.

Curve follows the MRS data of 40% solid. Interpretation of flat jack readings on the 60% solid are difficult. Only one area of contact out of nine was monitored, this data was most likely affected by differential loading.

PROPOSED LOAD/STRAIN RELATIONSHIP IN SITU

In general, the field observations are lower and less smooth than that of the MRS data. Placement of pack underground has several factors that are not considered in the MRS testing. Floor conditions, amount of debris and irregular surfaces will slow load development. Contact with the roof is made by building to within 150 mm (6") then adding fill pieces, usually softwood, until contact is made. The fill material is weaker than the hardwood and area of contact with the roof is typically a small proportion of the pack area. Greater amounts of strain are needed to generate equivalent loads to that of the MRS data.

Consideration of direct pack strain as opposed to indirect from roof convergence immediately next to the pack would allow use of the MRS data to predict load based upon strain.

Measurement of pack strain must be determined for the hardwood excluding fill material on top and debris if any. Reference points established to represent the movement of the top and bottom extremes of the chock blocks will enable determination of strain.

The relationship of load/strain of the MRS testing must be discounted to consider creep. Decrease in load when strain increase was stopped (Figures 4 and 5) illustrates time dependent deformation causing decrease in load. Observations of the loss over time was for a relatively short duration. Time dependent deformation decays exponentially with the majority taking place in that time frame.

An approximation of in situ behavior is presented in Figures 13 and 14. Trends are drawn based upon test results. The proposed curves are similar to the MRS data, falling below and increasing the difference with strain to intersect the lowest points at the end of the MRS curves. Extrapolation is made to 30% strain.

DISCUSSION

Results of field observations are generally lower than that of the MRS data. Trends of the curves are generally similar. Several factors contributed to this difference.

Loading characteristics are not equivalent for the two sets of data. MRS results are produced by a constant rate of strain over a short time span. Loading was normal to the packs. Underground closure is rarely normal to the packs. The rate of closure is not constant, it is comprised of rapid increments over a greater period of time.

Field observations of pack behavior are based on the contact area stress to determine load and convergence to determine strain. Flat jacks are typically used to monitor stress of the contact area. Several units placed in a pack will yield varying results. These differences are due to the non-uniform stress distribution through the pack and the inhomogeneity of the blocks. Deformation in the pack will also deform the flat jack causing error.

Convergence of the pack has often been measured indirectly. Pins in the roof and floor next to the pack have measured roof to floor closure. Pack closure may vary in soft floor. Pack reference pins are a better method of monitoring.

The nature of the environment causes problems with the procedures used to monitor load and strain. The characteristics described by the MRS

data portray ideal conditions. A proposed relationship between load and strain will allow determination of load indirectly by monitoring pack strain.

Monitoring of pack strain is technically easier and less expensive than monitoring load. Cost of instrumentation will be reduced significantly. The determination of pack load will be more precise due to the ability to measure strain more accurately than pack stress. The load strain curves produced from the MRS testing illustrate the high rate load increase over the initial 5% strain.

Restricting roof to floor closure is accomplished by developing a resistive force immediately behind the face. The development of the ultimate resistive force required will be enhanced if 1) placement occurs nearer the face, 2) the floor is clear of debris and 3) the pack is tightened to the roof. Failure to do so will allow initial closure without generating resistive force, the curve of load/strain would be shifted to the right.

CONCLUSIONS

1) The load/strain relationships of hardwood chocks from controlled testing in the mine roof simulator provides data on the optimum performances of the pack configurations tested.

2) Field generated data has inaccuracies due to monitoring methods and the nature of the mine environment. Results of field observations indicate lower load bearing capacities.

3) The proposed load/strain relationship represent a more realistic load bearing capacity.

RECOMMENDATIONS

1) The proposed load/strain relationships presented should be applied underground to determine load variations and compare them with various factors affecting load.

2) Future investigations of hardwood packs should incorporate pack strain measurement to indirectly determine load.

3) Alternative materials being considered for packing should be tested full or near full scale.

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Table 1 - Configuration of packs tested

Test No.	Configuration	% Solid	Height (m)
CBDC01	1.5 m x 1.5 m	100%	2.00
CBDC02	1.5 m x 1.5 m	80%	1.97
CBDC03	1.5 m x 1.5 m	50%	1.98
CBDC04	1.5 m x 1.5 m	30%	1.98
CBDC05	0.75 m x 0.75 m	100%	2.12
CBDC06	0.75 m x 0.75 m	60%	2.12
CBDC07	0.75 m x 0.75 m	40%	2.12
CBDC08	0.75 m x 0.75 m	40%	1.49
CBDC09	0.75 m x 0.75 m	40%	2.70

Table 2 - Summary of results - hardwood packs tested on mine roof simulator

1	2	3	4	5	6	7	8	9	10
Test No.	Configuration	% Solid	Height (m)	Contact Area m^2	Peak Load MN	Peak Load MN/m Run	Strain at Peak Load	Maximum Stress Over Contact Surface (MPa)	Stress Applied to Roof/Floor (MPa)
CBDC01	1.5 m x 1.5 m	100%	2.00	2.32	13.3+	8.7	9.6%	5.7	5.7
CBDC02	1.5 m x 1.5 m	80%	1.97	1.48	13.3	8.7	27.7%*	9.0	5.7
CBDC03	1.5 m x 1.5 m	50%	1.98	0.58	9.0	5.9	27.4%*	15.5	3.9
CBDC04	1.5 m x 1.5 m	30%	1.98	0.21	2.9	1.9	27.5%*	13.8	1.2
CBDC05	0.75 m x 0.75 m	100%	2.12	0.58	5.6	7.3	25.8%*	9.6	4.5
CBDC06	0.75 m x 0.75 m	60%	2.12	0.21	2.1	2.8	26.0%*	10.1	3.6
CBDC07	0.75 m x 0.75 m	40%	2.12	0.09	0.8x	1.0	22.4%	8.9	1.4
CBDC08	0.75 m x 0.75 m	40%	1.49	0.09	1.4	1.8	36.9%*	15.2	2.4
CBDC09	0.75 m x 0.75 m	40%	2.70	0.09	0.8	1.0	20.3%*	8.8	1.4

+Loading capacity of MRS reached before failure.

*Limit of MRS stroke reached before failure.

xSpecimen continued to support approximately 1 MN/m run until stroke limit was reached at 25% strain, however there was no evidence to suggest that the specimen capacity would increase if strain increased.

NOTE: Load and strain data have been adjusted to consider tare weight, friction, and point of initial contact. Corrections were derived by review of acquired data.

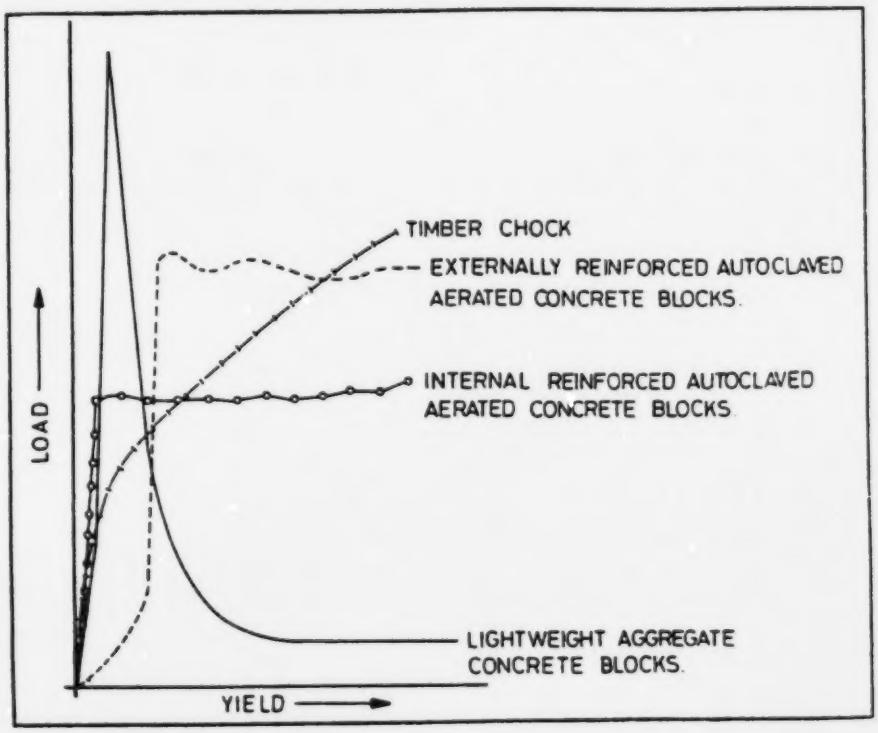

Figure 1 - General load/yield characteristics of various packing materials

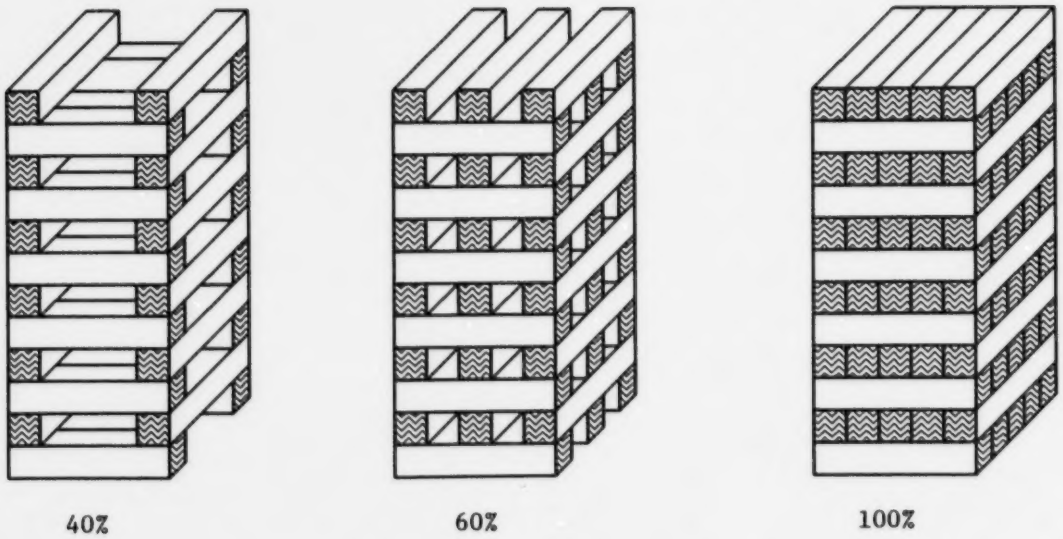

Figure 2 - Configuration of 0.75 m x 0.75 m packs illustrating 40%, 60% and 100% solid

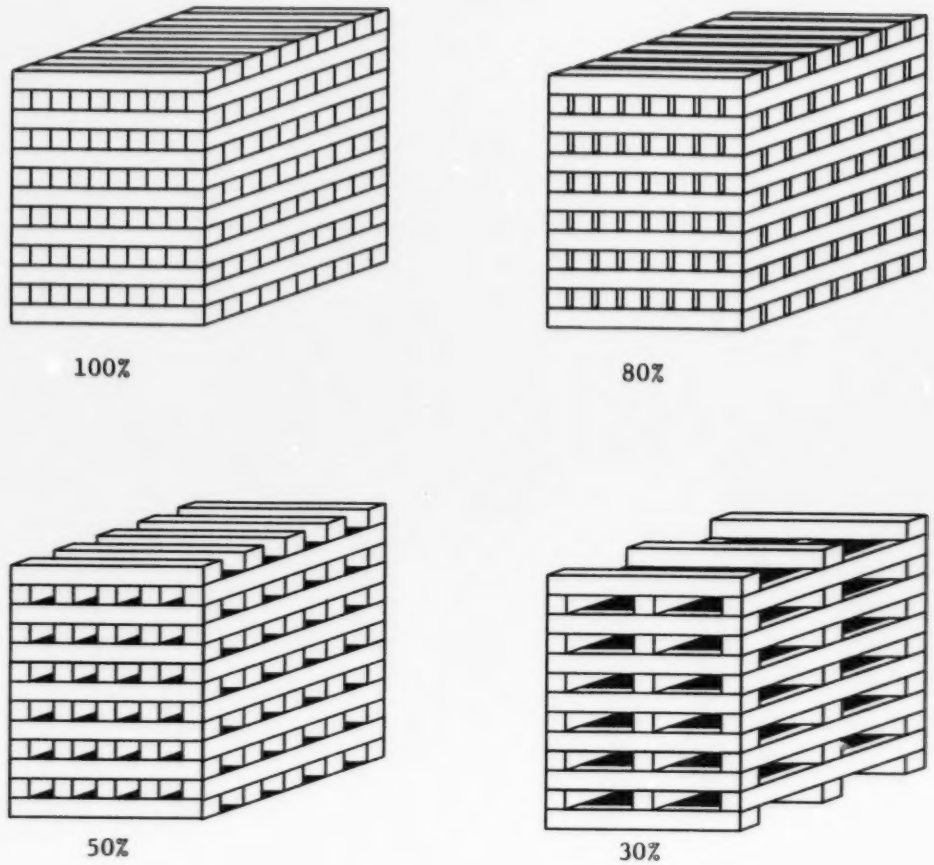

Figure 3 - Configuration of 1.5 m x 1.5 m packs illustrating 30%, 50%, 80% and 100% solid

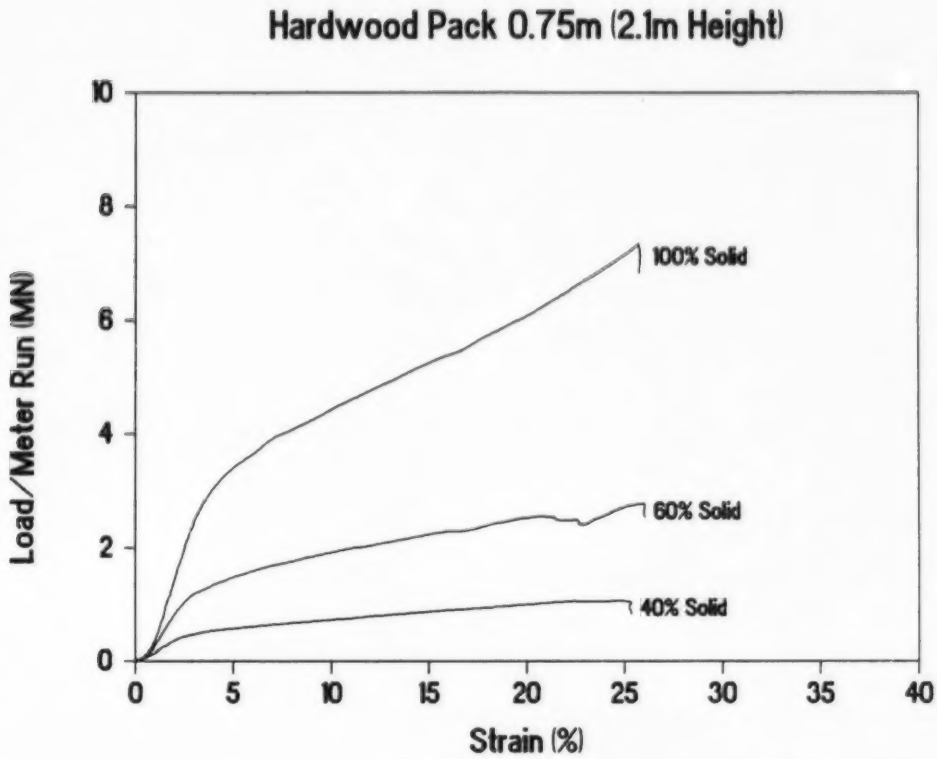

Figure 4 - MRS data, load/strain curves of 0.75 m x 0.75 m packs 2.1 m height

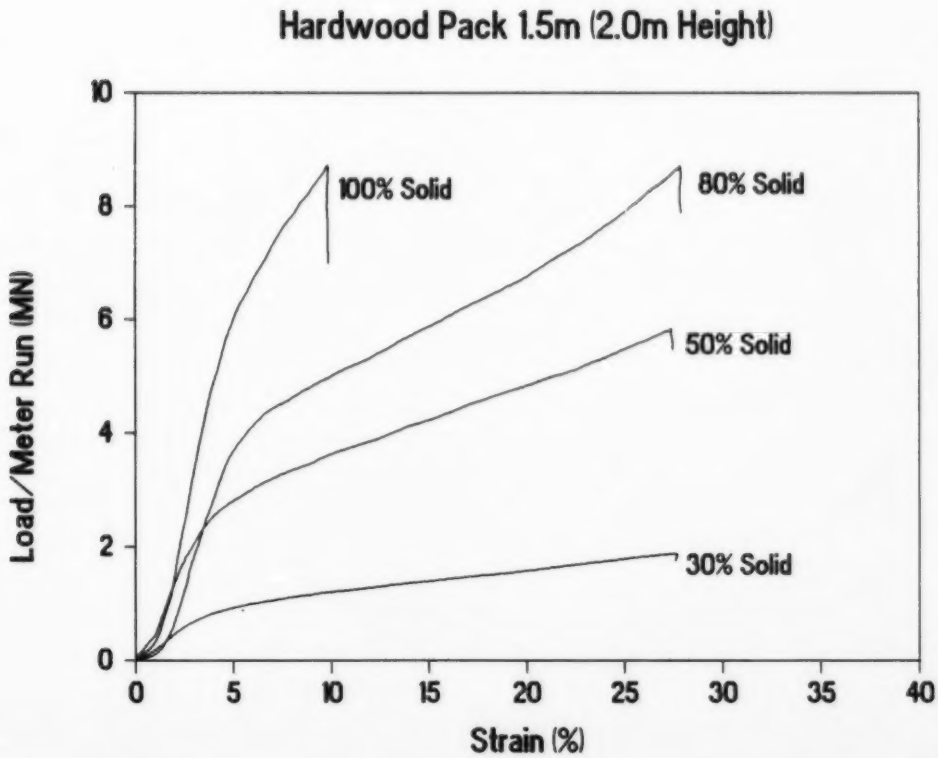

Figure 5 - MRS data, load/strain curves of 1.5 m x 1.5 m packs 2.0 m height

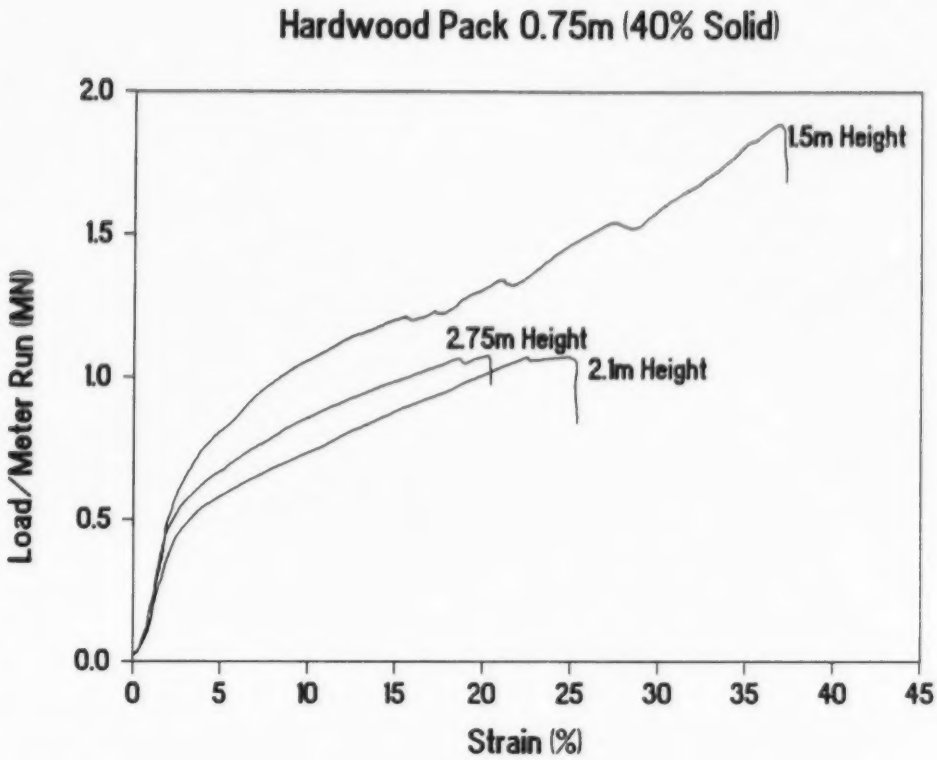

Figure 6 - MRS data, load/strain curves of 0.75 m x 0.75 m, 40% solid packs

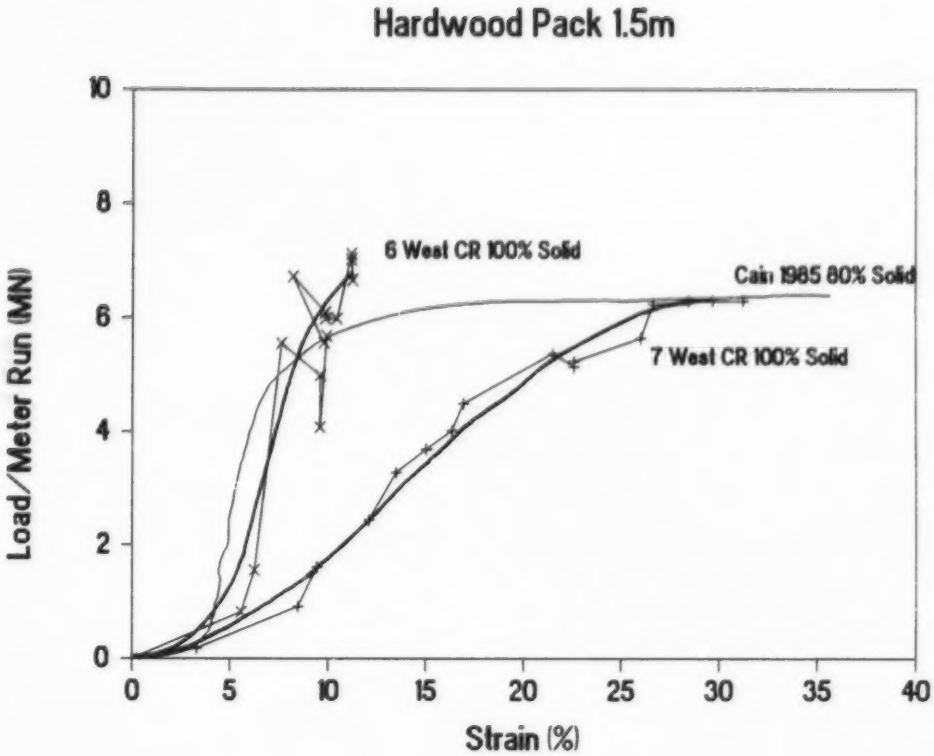

Figure 7 - Field load/strain curves with fitted trend of 1.5 m packs

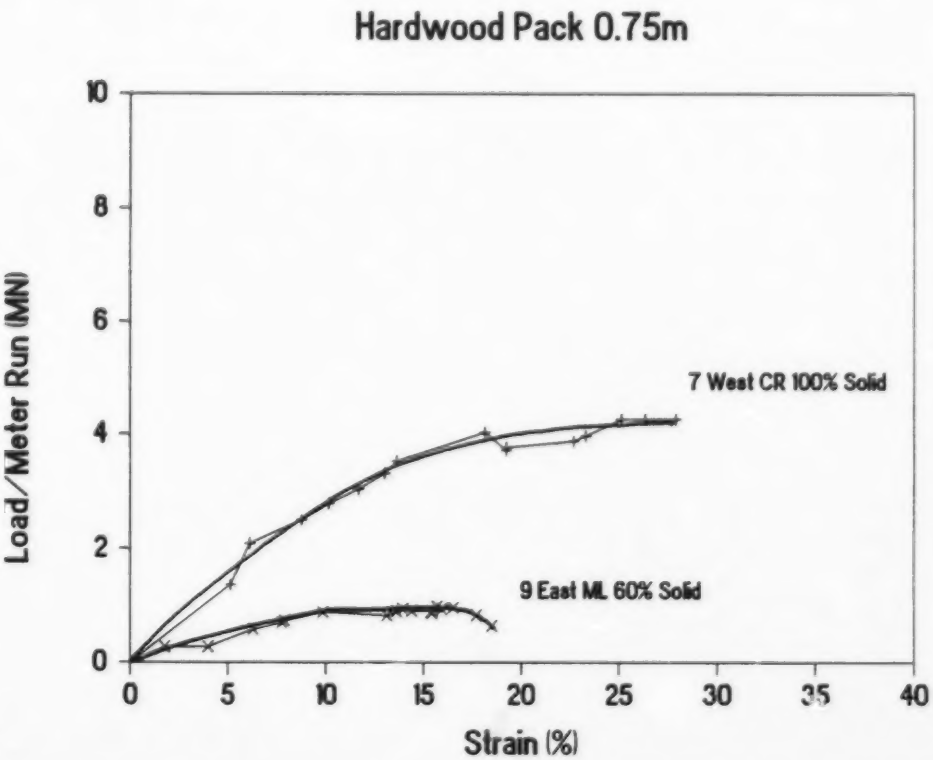

Figure 8 - Field load/strain curves with fitted trend of 0.75 m packs

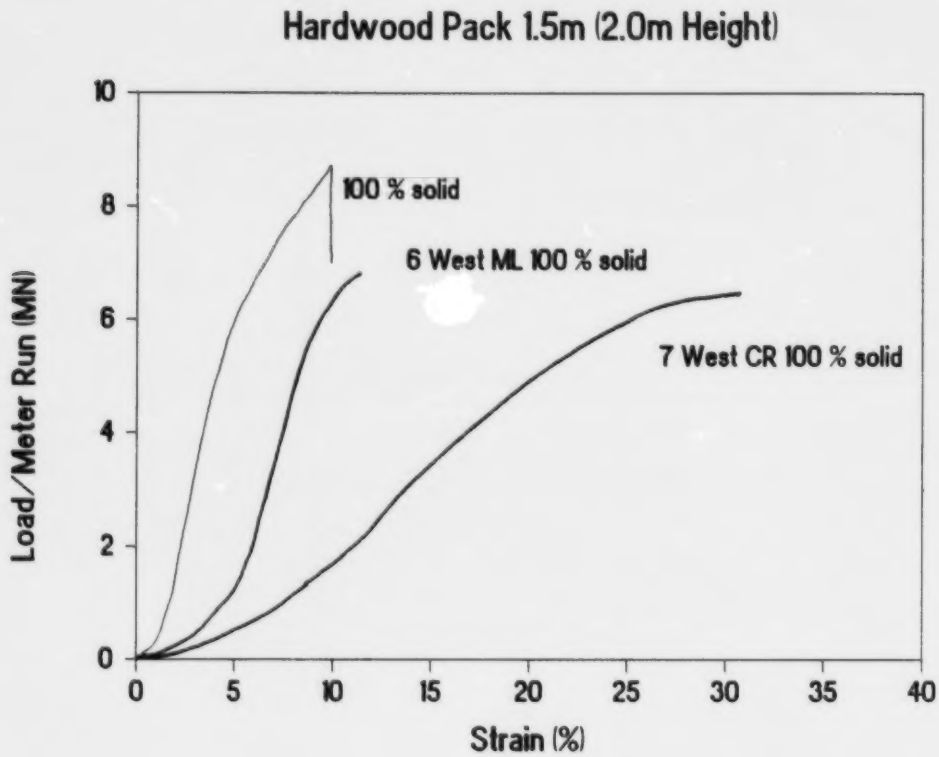

Figure 9 - MRS and field load/strain curves for 1.5 m packs, 100% solid

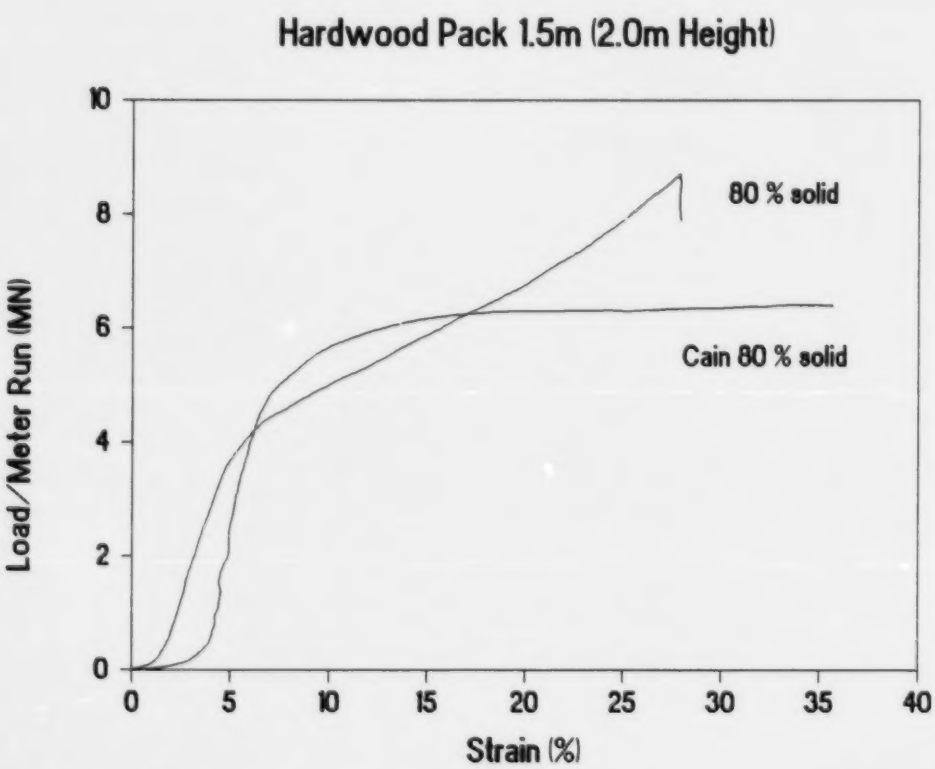

Figure 10 - MRS and field load/strain curves for 1.5 m packs, 80% solid

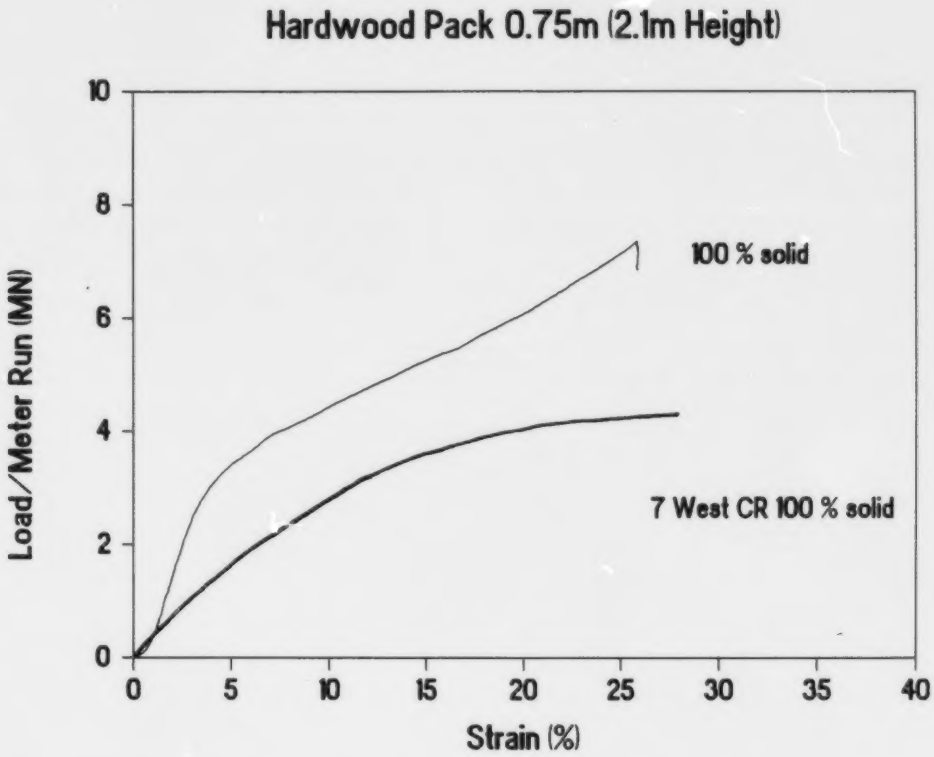

Figure 11 - MRS and field load/strain curves for 0.75 m packs, 100% solid

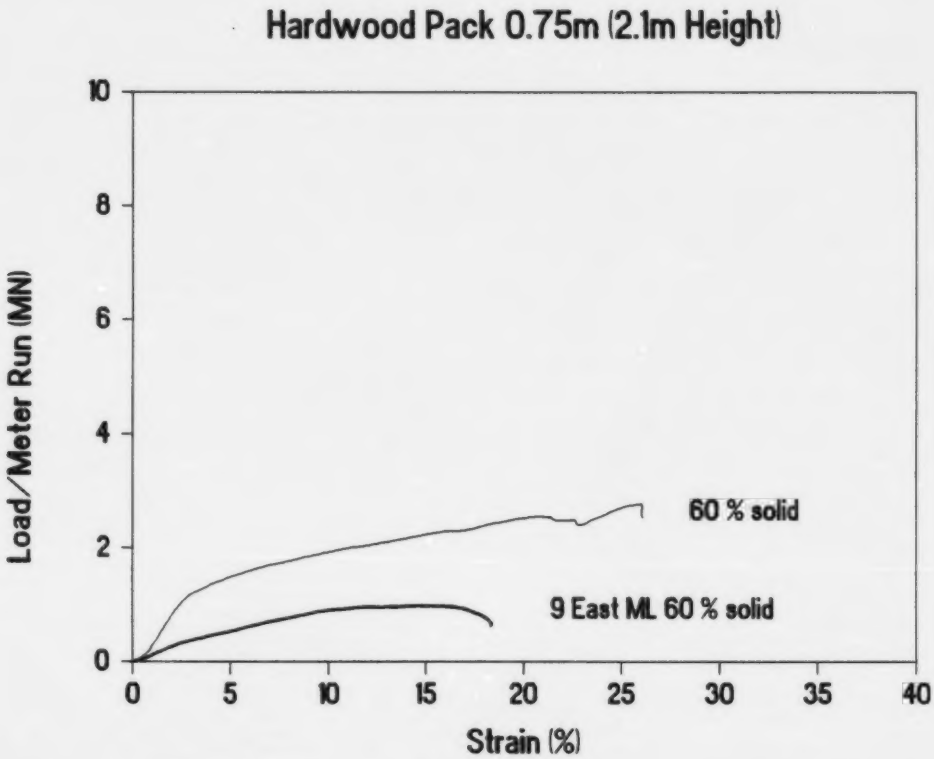

Figure 12 - MRS and field load/strain curves for 0.75 m packs, 60% solid

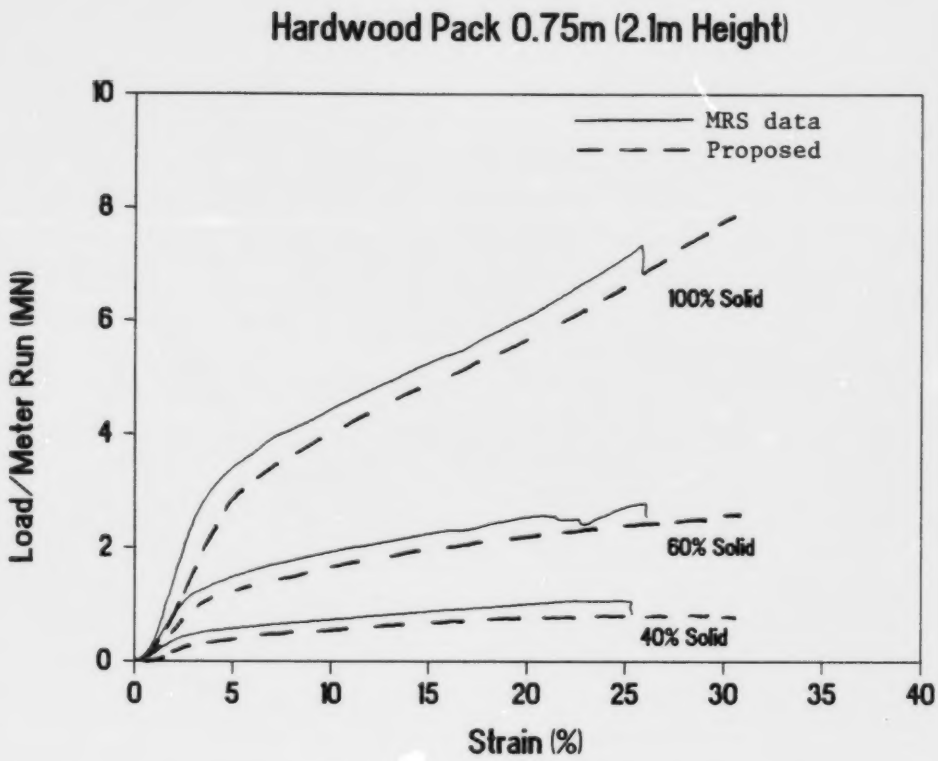

Figure 13 - MRS data and proposed in situ load/strain curves of 0.75 m packs

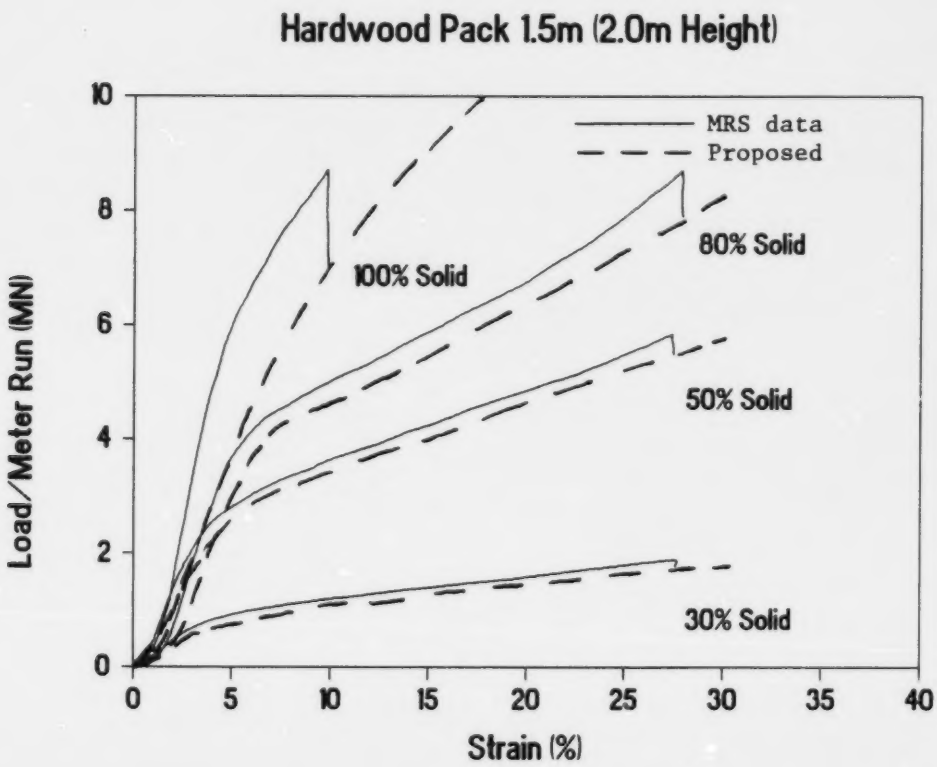

Figure 14 - MRS data and proposed in situ load/strain curves of 1.5 m packs